# Chapter 4
# Hydrologic Analysis of Enhancements to Existing Programs

## 4-1. General

*a.* Flood warning - preparedness program enhancements are developed with the members of the interdisciplinary planning team. Plan enhancements should be analyzed and evaluated based on general improvements over the existing condition, the cost of each component, and the potential contributions to reducing flood damages and preventing the loss of life. A strict economic analysis to explicitly quantified flood damage reduction benefits is not required. Reasonable estimates of flood damage reduction benefits based on specific actions that can be accomplished in the time afforded are required.

*b.* Flood-threat recognition systems and warning dissemination procedures should be evaluated based on how to enhance the desired response actions. For some systems, more formal arrangements for institutional and public response far outweigh the benefits of enhancements to flood-threat recognition systems. Simply implementing more hardware and software and incorporating a sophisticated monitoring and forecasting system does not necessarily provide a better overall program. For other areas they do provide needed additional warning time and reliability estimates.

## 4-2. Analysis of Flood-Threat Recognition Systems

*a. Preliminary evaluation of emergency response plans.* Some preliminary evaluation of the response plan is necessary to determine the type and scope of the flood recognition system. Develop a preliminary list of possible emergency response actions. Example response actions are listed below.

- Providing search, rescue, and evacuation services
- Scheduling closure of schools and transportation of students
- Curtailing electric and gas service to prevent fire and explosions
- Establishing traffic controls to facilitate evacuation and prevent inadvertent travel into hazardous areas
- Dispersing fire and rescue services for continued protection
- Establishing emergency medical services and shelters
- Closing levee openings
- Moving public and private vehicles and equipment from areas subject to flooding
- Relocating or stacking contents of private structures
- Initiating flood-fighting efforts (e.g., sandbagging, etc.)
- Establishing security to prevent looting

It is likely that some actions described above will not be appropriate for a specific community. List those beneficial actions that can be accomplished with the given resources of the community. Describe priorities, potential benefits, responsible parties, available resources, and approximate time required to accomplish the described actions.

*b. Data monitoring.* The objective of the measurement and detection task is to monitor developing hydrometeorological conditions. This includes current and near-term watershed conditions. Atmospheric parameters, measured rainfall, and current stream conditions can be observed. A knowledge of developing atmospheric conditions can yield information about the likelihood of future rainfall. Raingages provide an indication of the volume of water already on the ground. Stream gages provide the current state of the hydrologic conveyance systems that result in flooding. Stream gages provide the most important and reliable flood estimates. For moderate and larger streams the principal monitoring and forecasting from stream flow data are the primary basis of the estimates. Systems with raingages and stream gages provide additional warning time since the hydrologic system is being measured further upstream. By measuring rainfall and computing its possible impact on future stream flows, additional time is gained for an informed response. This is important for smaller streams. It is possible to begin response activities before significant amounts of runoff have reached the channel and detected by the stream gages. Adding meteorological monitoring enables determination if additional rainfall is moving into the area, is stalled, or is quickly on its way out of the area. Use of rainfall monitoring can enhance warning times. Incorporating a range of monitoring techniques provides more information to formulate forecasts and heighten the warning reliability.

(1) Raingages. Raingage measurements are point estimates of rainfall used to approximate the volume of water falling over an area. A raingage measurement is used as an estimator of the average of rainfall over a much larger area than the gage itself. The accuracy of the rainfall measured at such a point is less important than how consistently the point

measurement estimates the total rainfall over the area represented by that gage. For example, if the raingage accurately measures rainfall at a point but that measurement is an inconsistent estimator of areal rainfall, the gage has little value. However, if the rain gage measurement consistently estimates areal rainfall, the measurements are highly valuable, even if the point measurement is inaccurate. As long as any point measurement inaccuracies are consistently biased in one direction, the forecasts can be quantitatively or qualitatively calibrated to account for the bias.

(a) Number of gages. he number of raingages installed in a data collection system directly effects the quality of the data and the performance of hydrologic forecast models. The density of required raingages is based on the ability to provide an accurate estimate of the mean areal precipitation for the watershed. The minimum number is usually considered to be three gages. The maximum number is generally governed by the resources available and whether additional increases in flood warning time and reliability can be realistically achieved by increasing the gage density. Additional gages are often implemented in stages as more is learned about the system.

- The number of gages required depends on local conditions. Areas of higher rainfall variability generally require higher numbers of gages to estimate rainfall over a watershed adequately. Mountainous areas require more gages than flat lands. Areas subject to convective storms require more gages than areas subject to frontal type storms.

- National Weather Service guidelines recommend a minimum of three raingages and often use the following relationship between the minimum number of gages required (N) and the watershed area (A) in square miles (Schaake 1980).

$$N = A^{0.33} \qquad (N > 3) \tag{4-1}$$

Equation 4-1 is shown graphically in Figure 4-1 and illustrates how the minimum number of gages increases rapidly for areas ≤129.5 sq km (50 sq miles).

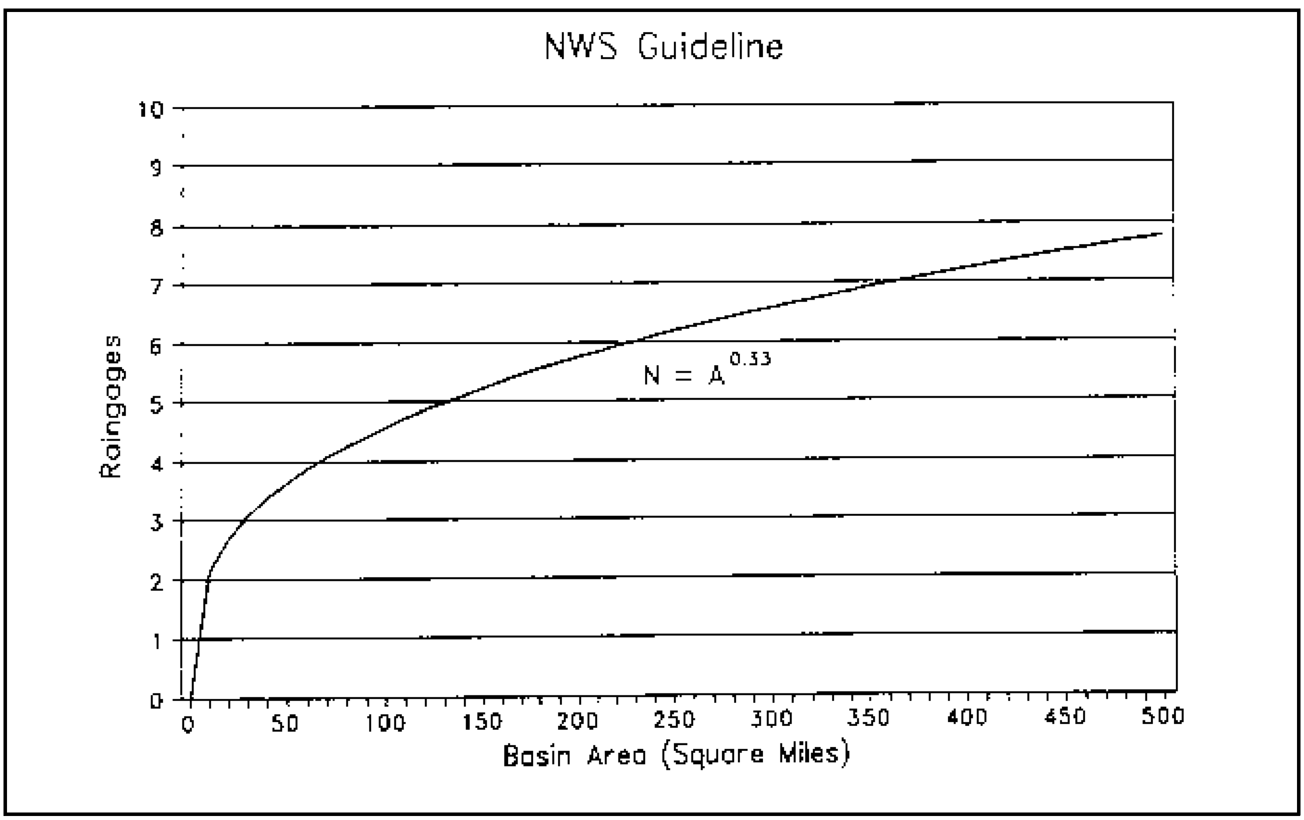


**Figure 4-1. Minimum raingage network size**

- The accuracy of a raingage network is judged by how well its *estimate* of the mean areal rainfall over the basin compares to the "true" value of mean areal rainfall. One measure of how well the network measures rainfall is a statistical parameter called the coefficient of variation ($C_V$). The coefficient of variation is the ratio between the standard deviation and the mean of a sample of measurements

$$C_v = \frac{\sigma}{\mu} \tag{4-2}$$

where

$\sigma$ = standard deviation

$\mu$ = mean

$C_V$ provides an indication of how close a measured value is expected to be to the true value. A low $C_V$ means that the measured value is expected to be near the true value with a high degree of certainty. A high value of $C_V$ indicates a much lower degree of certainty.

- For example, consider a relatively high value of $C_V$, say 0.25, for mean areal rainfall. This means that, for a measured mean areal rainfall value of 127 mm (5.0 in.), the true value of mean areal rainfall is expected to be in the range between 63.5 and 191 mm (2.50 and 7.50 in.) (i.e., $\mu \pm 2\sigma$) about 95 percent of the time. When $C_V$ is lower, say 0.05, the measurement is more certain. Then, for a rainfall estimate of 5.0 in., the true value of mean areal rainfall is expected to be in the range between 114 and 140 mm (4.50 and 5.50 in.) about 95 percent of the time, a much narrower range.

- Since flood forecast model performance is sensitive to the accuracy of rainfall estimates, narrowing the range of possibilities for the true rainfall amounts translate directly to more accurate and reliable forecasts. Therefore, the coefficient of variation is a reasonable surrogate to use to evaluate improvements in forecast accuracy. An empirical equation is available (GKY & Associates 1981) to estimate the coefficient of variation of the mean areal rainfall

$$C_v = 0.082 T_{obs}^{-0.22} \left( \frac{N}{A} \right)^{-0.602} \tag{4-3}$$

where

$T_{obs}$ = observation period in hours

$A$ = basin area

$N$ = number of gages

The appropriate observation period for a flood warning situation is a balance between waiting long enough to get sufficient information and getting a forecast out soon enough to be valuable to the recipients. Assume a reasonable time to monitor the developing storm is equal to 25 percent of the basin time of concentration. Then the time, $T_{obs}$, required to observe a storm is

$$T_{obs} = \frac{T_c}{4} \tag{4-4}$$

The network size, N, is selected to reach the desired level of accuracy as defined by $C_V$. Now, since $T_{obs}$ is known from direct analysis of watershed records or it is estimated from watershed characteristics, $C_V$ is a function of the number of raingages for a given watershed of size A. The network size, N, is selected to reach a desired level of accuracy as defined by $C_V$. To illustrate the impact of network size on $C_V$, consider a given watershed having a specific $T_C$ area and corresponding observation time. Using equations 4-3 and 4-4 and presenting the results graphically as shown in Figure 4-2, one can see very clearly how adding gages to a relatively small network dramatically improves network accuracy. Eventually, however, the gains in accuracy diminish to insignificant levels for each additional gage. This could be shown for any given watershed in the same manner.

- The diminishing return of network performance for additional gages provides important information for network size. The accuracy of rainfall measurements is a vital aspect of any hydrologic model performance in a flood warning - preparedness program. In fact, model performance is much more sensitive to errors in the rainfall input than to errors in any other parameter - especially in flash flood situations. Therefore, it seems reasonable that a measure of rainfall accuracy such as $C_V$ can be used as a surrogate measure of hydrologic model performance. Equations 4-3 and 4-4 can be used to develop a curve, as in Figure 4-2, for any watershed to help determine the sensitivity between the number of gages and the estimate of basin average precipitation.

- The information described above will help determine the minimum and most effective number of gages for an initial estimate. The cost and amount of Federal and local sponsor resources available for

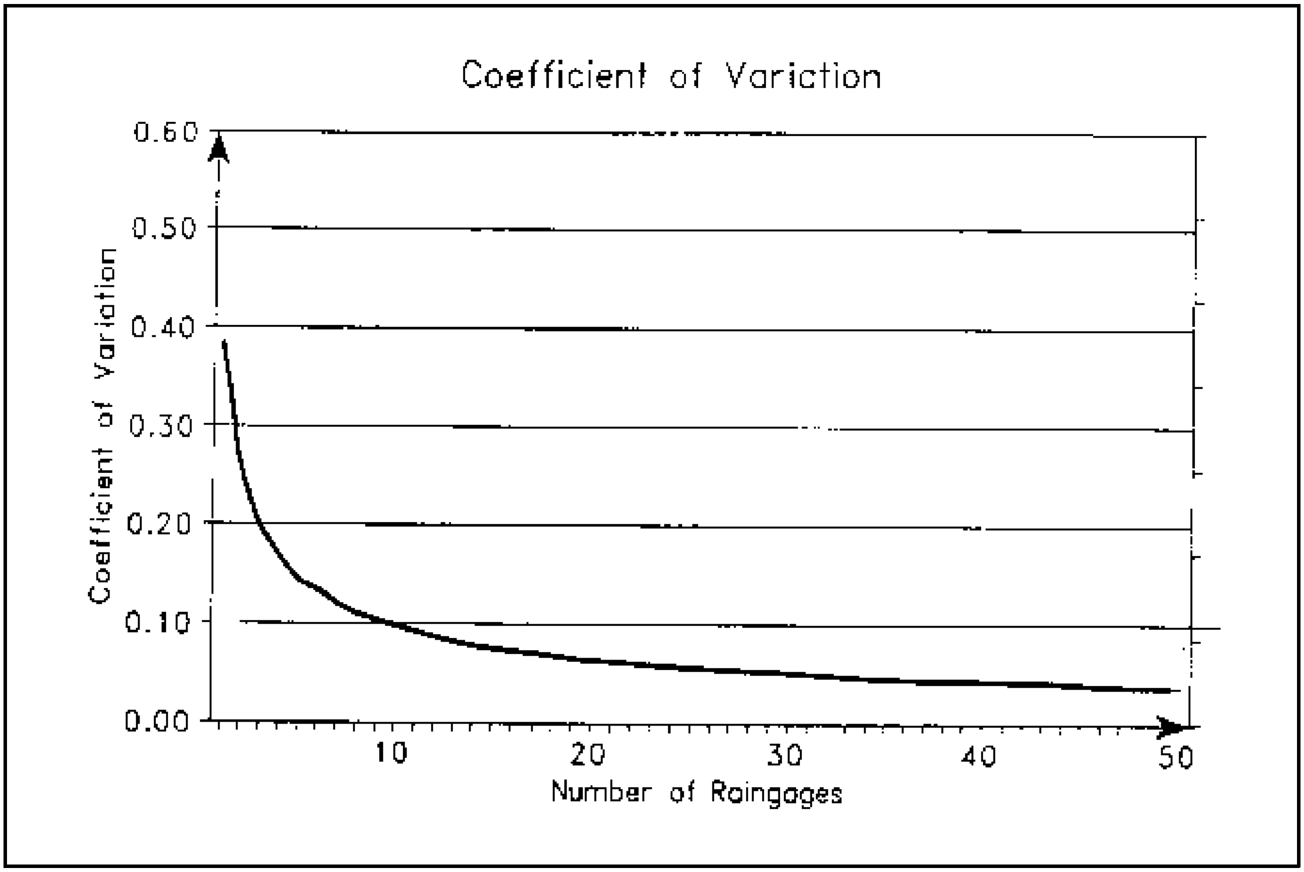


**Figure 4-2. Relative accuracy raingage network**

a gage network will generally require a downward revision of the initial estimate of the number of gages. Example costs of flood warning - preparedness plan components for a typical ALERT type system are shown in Appendix E. The location of the rain gages, described below, will likely further modify the selected number of gages.

(b) Location of raingages. Once the number of gages needed is estimated, the location of the gages is determined. The initial estimate of the number of raingages based on watershed size and rainfall variability will normally be revised based on gage location. The following factors should be considered when determining the location of raingages.

- Hydrologic engineering judgement, knowledge of storm and rainfall-runoff characteristics
- Requirements of line-of-sight radio telemetry to base station
- Gage accessibility for maintenance and potential for vandalism at the site
- Terrain slope and orographic effects
- Potential usefulness for other purposes
- Location of existing gages
- Gage redundancy
- Necessity for monitoring storms before the reach the watershed - (When warning times are very short, it may be desirable to sample storms before they reach the watershed. In this case, it may be prudent to locate gages outside the watershed. Due consideration for the likely tracking of storms across the area is important in determining the location.)

Appendix C provides additional information on raingage siting as related to gage exposure (NWS 1972).

(c) Types of raingages. The most common gages measure rain by volume or weight. The most popular rain measurement device for automated measurement and detection systems used for flood warning is the “tipping bucket" gage sized to measure rain in 1-mm (0.04-in.) increments. This type of gage is illustrated in Appendix B, Figure B-1. The type of raingage selected is based on availability, cost, reliability, and vender support, in addition to installation, operation, and maintenance considerations.

(2) Stream gages. Stream gages provide information about the current state of the hydrologic response system. A typical pressure transducer type stream gage is shown in Appendix B, Figure B-2. For flood recognition systems without sophisticated forecasting, stream gages may be the only gages needed. This is especially true for watersheds where the warning time is sufficient to respond based on a stream gage upstream of the damage site. As forecast tools, the effectiveness of stream gages varies. In larger watersheds where downstream forecast points are dominated by routed flows, upstream stream gages are important indicators of future flows. However, in flash flood events dominated by local runoff, stream gages become little more than verification tools, confirming current flood forecasts rather than adding significant value to them.

(a) Stream gage alarms set to sound at certain levels or programmed to detect rapid changes in water level can recognize events that other "upstream" monitoring systems could possibly miss.

(b) The location of stream gages in an automated flood warning - preparedness program is determined to satisfy two elements: public warning requirements and hydrologic forecasting and associated watershed modeling requirements. First, a stream gage should be located where forecast stages are required. Key potential damage points or well-known locations that the general public can relate to are important potential gage locations. Stage alarm gages should be located at key damage points *and* key points at sufficient distance upstream to yield enough warning time to be of value. If the watershed is large enough to require the definition of hydrologic subwatersheds, stream gages should be located at the subwatershed outlets to facilitate hydrologic modeling. General considerations for the location of any stream gage for proper operation includes the following:

- Location subject to minimum scour and deposition.

- General course of the stream that is straight for 100 m upstream and downstream of the gage location.

- Total flow confined to one channel for all stages.

- Location within a reach satisfactory for measuring discharge for all stages near the gage.

- Location far enough upstream of the confluence of another stream or tidal influence.

In addition, many of the same items pertaining to the location of precipitation gages, as indicated above, must be considered when determining the location of stream gages.

(3) Radar estimates of rainfall. The possibility of using radar to estimate rainfall has intrigued hydrometeorologists for many years. Raingages provide adequate measures of rain falling at a point but are less proficient at estimating areal rainfall. Radar, on the other hand, can observe rain falling over wide areas. However, radar estimated amounts of rainfall over specific areas are often inaccurate.

(a) Radar analysis of rainfall depends upon receiving electronic signals bounced off rain drops. Many things interfere with signal quality including obstructions such as buildings and mountains, mixed precipitation (snow, sleet, hail), the curvature of the earth, and anomalous signal propagation, to name a few. Despite these difficulties, new technologies are improving abilities to estimate rainfall with radar.

(b) Since raingages are accuratae for measuring rainfall at a point and radar is sensitive in detecting the areal extent of rainfall, the ideal situation would be to combine the two techniques. Real-time raingage measurements can be used to calibrate radar estimates to provide a "best estimate" of the true volume of rainfall entering a watershed.

(c) The use of radar together with a network of raingages can reduce the number of fixed gages needed to achieve the same level of accuracy in the estimate of areal rainfall. Crawford and Andra (1987) demonstrated that the sampling quality of a 31-raingage network in Tulsa, OK, could be matched with radar plus just three fixed gages in the field. In addition, for the radar/raingage combination, Crawford and Andra showed that all gages in that network above 10 to 15 were essentially redundant; the additional gages provide no new information.

(4) Meteorological forecasts. Forecasts of developing meteorological conditions are especially useful in getting an early start in analyzing potential emergencies and in extending current forecasts. Meteorological forecasts of severe weather can alert forecasters to conditions that could lead to flooding should the storm materialize. Early precautions can be taken.

(a) Current flood forecasts can be extended using meteorological forecasts. Forecasts solely based on measured rainfall when it is still raining hard are likely to under estimate the actual flood. Therefore, a prudent forecast should include information about the continuing meteorological conditions.

(b) In rapidly responding watersheds, meteorological forecasts may be the only effective tools to provide adequate flood warnings. Waiting for observed rainfall and river measurements in these situations introduces too much of a delay. The flood may come and go before the message gets out.

*c. Data transmission subsystems.* Once hydrometeorological parameters are measured in the field, they must be transmitted to a central location for analysis. The type of forecast situation will dictate the most appropriate method for data transmission. Obviously, speed and reliability are critical to flash flood warning - preparedness programs. Several ways of automatically collecting data from remote locations are in use. They include interrogation, event reporting, timed reporting, and various combinations of these techniques. Each technique has its place. Which technique to use depends on the application and individual preferences.

(1) Interrogation. Interrogation techniques are, perhaps, the oldest of the automated data collection techniques. Here, a central station "calls" a remote data location and "asks" for the data. The remote site responds by sending back the data. Common examples include telephone and radio-based interrogation systems. A computer may use a telephone circuit or radio link to contact a remote site to request data. The equipment at the remote site responds to the request and returns the data to the computer. A group or network of remote sites are contacted sequentially. When the computer finishes talking to one site, it contacts the next station.

(a) Interrogations or requests for data from a network of remote gaging locations are normally set up on a routine fixed schedule. Fixed intervals can be set for every 30 min, every hour, every 6 hr, every 24 hr, etc. At the scheduled interrogation time, the central computer automatically calls each site and collects the data. When a data collection cycle has completed, the computer will wait for the next appointed time to begin the collection cycle again.

(b) If the data show that field conditions are changing rapidly, the interrogation schedule can be changed to retrieve data more frequently. Sometimes the schedule is changed manually by an operator. Sometimes the computer is programmed to detect opportunities to increase or decrease interrogation frequency automatically, as conditions warrant.

(c) Interrogation systems are two-way communication systems. Central data collection sites and remote data sites have both receive *and* transmit capabilities. One has the opportunity to contact a remote site at anytime to verify system operation or to collect data between normally scheduled interrogation times. Two-way communication also means that more equipment is required at remote sites (as opposed to one-way systems), since both receive and transmit functions must be supported. Power requirements are higher with interrogation systems, since radio receivers must be on continuously to listen for interrogation requests.

(d) Reports from an interrogation system inherently "lag" the monitored event. In situations where field conditions change rapidly, reports may not get to the user in a timely manner. For example, if 3-hr interrogation intervals are used and a major rainstorm occurs in the first hour after a scheduled interrogation, two additional hours will pass before the user gets the new data. Even if the interrogation schedule is immediately increased, a significant amount of potential response time is lost. In addition, intensity information can be lost since the data are interpreted as occurring over a 3-hr period instead of concentrated in the first hour. Such a lag in reporting and loss of intensity information can be important in a critical response situation like a flash flood.

(2) Timed reporting. Timed reporting systems are one-way communication systems. Data reports are transmitted from remote sites at regularly scheduled intervals without prompting from a central computer. Each remote location is allotted a small "window" of transmission time. At the appointed time, the remote site turns on its transmitter and sends the data. If, for some reason, the remote site misses its scheduled transmission, it must wait until the next transmission time to send the data.

(a) The GOES satellite system is a good example of a timed reporting system. Each data platform in the network has a designated time to transmit. The data platform sends data to the satellite that relays it to the ground receiving station. This approach requires accurate clocks at the remote sites to choreograph the intricate "data dance" through the network. Without accurate clocks, the data reporting schedule would quickly turn chaotic.

(b) Timed reporting systems are excellent for routinely collecting data on a set schedule. One-way communication for timed reporting also lowers power requirements. However, since the systems communicate in one direction only, they lack the flexibility to respond to changing field conditions.

(3) Event reporting. Event reporting systems also communicate in one direction only. However, the hallmark of these systems is their ability to generate data reporting rates that are directly proportional to the rate of change of the monitored conditions. Event reporting systems generate data reports from remote locations as soon as "events" are

detected. An event can be defined as the occurrence of a given incremental change. For example, consider a tipping bucket raingage that "tips" after receiving one millimeter of rainfall. Each tip generates a report that is immediately transmitted to the central station. As the storm intensity increases, the tips occur more frequently and more reports are generated. As the storm intensity diminishes, the reporting rate decreases. The rise and fall of the data reporting rates exactly match the ever changing storm intensity.

(a) Data reporting rates that directly mimic the rate of change of environmental conditions make event reporting systems ideal for applications where response time is limited. In small watersheds, the time between the occurrence of intense rainfall and the onset of flooding is short, often a few minutes or hours. Event reporting systems provide immediate indications of intensity changes that maximize potential response time.

(b) Event systems require very little power. Most of the time the remote site is quiet or off. When an event occurs, the remote unit is briefly turned on to transmit a short data message (nominally 0.25 sec). The unit turns off again and waits for the next "event" to occur before transmitting again. For raingages with 1-mm tipping buckets in climates receiving 1,000 mm (40 in.) of rain per year, the total amount of data transmission time is about 7 or 8 min per year.

(c) Each remote data site in an event reporting system acts independently. Whenever an event is detected, the remote site immediately transmits its data. Such independence creates opportunities for messages from two or more remote sites to collide with a resulting loss of data. To protect against unacceptable data losses, two measures are normally employed. First, data messages are kept as short as possible. Short messages decrease the potential for message collisions. Secondly, data messages are composed with information that enables data recovery from future messages. For example, raingage data is reported as an accumulated value. If a data report is lost, the next successful message contains the new total. Thus, no volume information is lost. Only the timing information for the "missing" millimeter of rainfall is lost.

(d) In well designed event reporting radio systems, data loss due to collisions is minimal. Far more data are lost because of other radio interference or poor radio paths. Relatively large numbers of gages can be accommodated. Individual event reporting systems receiving data from more than 500 gages are in successful operation.

(e) Event reporting systems generate reports when an "event" or "change" occurs. What happens if nothing changes for a long time (e.g., long periods between rain storms)? How do users know if the system is operating during quiet periods? Normally, event systems are designed to report automatically at least twice per day with a message indicating its operational status. A central computer is often programmed to sound an alarm when the expected status signals are not received.

(4) Mixed reporting. Technical advances have produced more intelligent and capable remote units that combine interrogation, timed, and event reporting modes. In many cases, new technology allows users to take advantage of the best that each technique has to offer, all in one package. For example, with mixed reporting, a user could define a routine interrogation schedule to ensure receiving data at fixed intervals. At the same time, the remote unit could be programmed to transmit a data report spontaneously when an event has occurred, achieving the responsiveness of an event system. The Geostationary Orbiting Environmental Satellite (GOES) satellite system is an example of a mixed system. Routine data reporting is done through timed reporting. However, an event channel is available for emergency use if rapidly changing field conditions are detected by the data collection platform.

*d*. *Communications media*. Several different types of communications media are available to transport information to and from remote locations. Satellite, telephone, meteor-burst, and VHF/UHF have all been used successfully for automated data collection.

(1) Telephone. Telephone systems are frequently used in automated data collection systems. The initial costs are low, and the data transfer rates can be quite high (2,400 baud or greater on voice-grade lines). Two types of telephone systems are in common use, dial-up and leased-line. Leased-line systems have dedicated telephone lines (leased by the user) that are continuously connected to a remote site. The user can request data every few seconds if necessary. Leased-line is a direct "hard-wire" connection to the remote site. It can be expensive, of course, since the user has total and continuous control of the telephone line.

(a) Dial-up systems are a less expensive telephone alternative. The telephone lines are not continuously connected to the remote site. Whenever data reports are required, the remote site is dialed up just like one person calling another. When data reporting is finished, normally in a minute or less, the line is disconnected. Actual line usage is quite short.

(b) Telephone systems have their advantages but are not generally recommended for flood warning - preparedness programs. Reliability during storm conditions is always a concern. Telephones often fail under the very conditions that require maximum data system integrity. In addition, telephone access is not always available for remote gages, particularly in mountainous or rural areas. Even when it is generally available in these areas, the costs to get telephone service directly to the data collection site may be prohibitive.

(2) Satellite. Large area data collection is often accomplished using satellites. Data collection platforms can be deployed hundreds or thousands of miles from the central computer. Data are transmitted to a satellite in an earth orbit and relayed to a ground receiving station. A single satellite can relay data from anywhere in its "viewing" area to the ground station.

(a) Two types of satellite systems are in general use: polar orbiting and geostationary. Polar orbiting systems use satellites in a relatively low orbit roughly 805 mm (500 miles) above the earth's surface. These systems are constantly moving with respect to a fixed location on the earth's surface. The ARGOS system, jointly administered by France and the United States, is an example of this type operation. Low orbit satellites like ARGOS pass overhead approximately twice per day. When the satellite comes within range, a data collection platform transmits its information to the satellite for temporary storage. When the satellite passes within range of a ground station, the data are retransmitted to the ground station. Low orbit satellites are generally used in applications where time is not a critical factor.

(b) The most commonly used satellite system for hydrologic data collection is the GOES system. This system employs satellites deployed in a high earth orbit approximately 37,000 km (23,000 miles) above the equator. At this altitude, an orbiting satellite moves at the same angular velocity as a point on the earth's surface. This allows the satellite to remain in a fixed position relative to points on the earth's surface.

(c) The GOES system is primarily a timed reporting system. At precisely defined times, the remote data collection platforms "wake-up" and transmit their data to the satellite for immediate relay to the ground station. Generally, these transmission times are scheduled once every 3 hr. To handle emergencies, an event reporting capability is also available. If the data collection platform detects an unusual event, the platform spontaneously transmits its information, which is immediately relayed to the ground station.

(d) The GOES system is excellent for retrieving data from large areas. However, since ground stations are relatively expensive, small users must rely on state and Federal agencies to operate them. Data are often distributed from the ground station computer by telephone. The expense, timed reporting limitations, and telephone connections limit the GOES system's effectiveness for time critical situations like flash flood detection.

(3) Meteorburst. Although not often used, meteorburst communication techniques have been used successfully to collect data for hydrologic purposes. This technique uses naturally occurring meteor trails to augment long distance communication.

(a) Every day, the earth's atmosphere undergoes billions of high-velocity encounters with pieces of cosmic debris otherwise known as meteors. As they enter the atmosphere, friction converts their kinetic energy to heat. The temperature of the incoming particles rises and their surfaces begin to erode, leaving behind a trail of ions. These trails have the property that incident radio energy is either reflected or reradiated. Meteorburst communication systems use this property to relay radio signals.

(b) A typical meteorburst system is an interrogated system. A central computer station sends its signals toward the top of the atmosphere where meteor trails are likely. Though the life of a meteor trail is short (a few milliseconds to a few seconds or so), an individual trail can retain its peculiar radio relay capacity long enough for a signal to bounce off the trail and back down to a remote data platform. The remote platform must immediately respond by sending its data along the same path before the trail disintegrates. Although, this communication technique appears to be a "hit or miss" proposition, a sufficient number of trails occur to keep the average waiting time for a usable trail on the order of minutes.

(c) Meteorburst systems in use today include the SNOTEL system in the western United States, the hydrologic data collection system for Alaska, and a tsunami detection system on the coast of British Columbia. The SNOTEL system maintains remote data platforms throughout the mountainous western states to monitor snowpack conditions to forecast future water supplies. In Alaska, statewide hydrometeorological conditions are monitored hourly. Tide stations linked to a central computer by meteor communications stand watch for sudden changes in ocean levels along the Canadian west coast that may precede a tsunami.

(d) Meteorburst systems are appropriate for long distance communications without an installed relay such as a radio repeater or a satellite. Up to 2,000 km can be covered in a single "hop." Meteorburst systems also work extremely well in far northern latitudes where geostationary satellite coverage is limited. However, the responsiveness of a meteor communications system still relies on the occurrence of appropriate meteor trails. The occurrence of usable trails varies daily and annually. If an emergency such as a developing flash flood occurs during a time of very light meteor activity, communications may not be adequate.

(4) VHF/UHF radio. Radio systems using VHF frequencies (near 170 MHz) and UHF frequencies (near 450 MHz) are often employed where communication distances are relatively short. VHF/UHF systems are often called "line-of-sight" systems. Literally, if one can see it, one can communicate with it. To communicate over the horizon or around obstacles such as mountains or tall buildings, radio repeaters are required.

(a) VHF/UHF systems are generally under total control of the local user. Event reporting techniques can be used easily. Interrogations in two-way systems can be done anytime. Therefore, radio systems are in frequent use monitoring local events in a highly responsive mode. Flash flood warning systems for individual communities commonly use radio-based systems.

(b) Event reporting technologies are commonly used in automated community flood warning systems. Data reporting rates determined by the intensity of the monitored storm conditions provide precise information about rapidly changing field conditions at exactly the right moment. Peak rainfall intensities generate peak rainfall data reporting rates. Peak rates-of-rise of water surfaces also generate peak water level data reporting rates. Both sets of information are critical when determining the genesis of flash flooding.

(5) Communications system selection. The type of communications system used in a flood warning system depends on the scale and time requirements of the local flood warning - preparedness programs. Typically VHF/UHF systems are employed for smaller scale applications where two or fewer repeaters arranged in series are required to communicate from remote gage location to the base station. More than two repeaters in series are too risky, since failure of one repeater causes the link to fail. Satellite and meteor-burst systems are employed in larger regionally or nationally based systems. Table 4-1 provides additional guidance for communication selection based on watershed response times.

*e. Base station configuration.* Microcomputers are the central feature of automated flood warning systems. These machines manage and control the crucial flow of information. Data from remote data platforms can be received, checked, and stored for later use. Various displays can be used to present data visually. Application programs can use the data to calculate the extent of flooding. Results can be sent to emergency response officials.

(1) The microcomputer-based information management center, often referred to as the "base station," consists of a microcomputer with the appropriate telephone, satellite, meteorburst, or radio communication equipment. Additional peripheral equipment required includes printers, modems, and standby power sources.

**Table 4-1**
**Communication System Selection**

| Watershed Response | Communication System |
|---|---|
| 0-3 hr | Radio |
| 3-6 hr | Radio<br>Satellite |
| 6-12 hr | Radio<br>Satellite<br>Meteorburst |
| >24 hr | Radio<br>Satellite<br>Meteorburst<br>Telephone |

(2) Data acquisition, data display, application programming, and dissemination are not the only functions performed by automated flood warning computers. Rapidly advancing microcomputer technology makes the number and type of information management functions virtually limitless. Nevertheless, these four functions are basic and key to the success of many flood warning systems.

(3) Whether the data reporting system is interrogated, timed, event, or mixed, the microcomputer is responsible for coordinating data recovery. Once data have been acquired, its quality must be checked immediately. Quality checks can be as simple as checking if the incoming data value is within the expected range of data. More sophisticated quality checks use encoding and decoding algorithms to detect if transmission errors have occurred. If the data pass the quality tests, a database file is created. Otherwise, the data are discarded.

(4) Data quality are critical. Poor quality data can be misleading, causing false alarms, unreliable forecasts, or no response when one is required.

(5) Filed data are available for use in data displays, application programs, and for dissemination or other possible uses. Databases for automated flood warning systems need to be large enough to hold data for several months or even years. If not, some provision must be made to transfer data to a permanent storage file. Data are essential for future analysis to understand the hydrologic response of watersheds and refine hydrologic forecast techniques.

(6) Immediately after data reception and filing, the data are checked for possible alarm conditions. If excessive rainfall intensities or rapidly rising stream levels are detected, an alarm can alert the system operator.

(7) A variety of displays can be used to present information to users visually. Data reports, graphs, and maps are commonly used. These displays can be shown on high resolution color monitors or sent to a printer to obtain a permanent copy.

(8) Text reports are used to summarize key data in useful time increments such as 30 min, hourly, daily, etc. Graphs are used to examine trends. Maps are used to examine the geographical variation of data. Each is beneficial in its own way to convey information to the user.

(9) The following list (Federal Interagency Advisory Committee 1985) summarizes the minimum features expected of software used in an automated flood warning system:

- Precipitation and stream gage data collection
- Quality control of input data
- Historical databases
- Display of precipitation data in tabular or map form
- Display of stream gage data
- Visual and audible alarm based on excessive precipitation rate or rate of river rise
- Hydrologic models (optional)
- Advisory forecast information (optional)
- Link to NWS office

*f. Forecast Preparation System.* The most common application programs in automated flood warning systems are the runoff and river forecast programs. These programs utilize observed and, in some cases, forecast rainfall amounts to compute runoff that will enter the stream system. Forecast programs usually update their results automatically, sometimes as often as every 5 min. When a forecast program determines that dangerously high streamflow may occur, an alarm can sound to alert the operator. Since forecast preparation is automated, the system must be able to handle a variety of situations quickly. A robust data-error-handling capability must be incorporated to avoid generating warnings based on erroneous data that is too high or generating no warnings because errors caused low forecasts. Missing data must also be handled properly. A smoothly operating system shouldn't be halted simply because data from a gage for a particular time period are missing. Missing data should be estimated from surrounding information and/or the operator should be requested to intervene.

(1) Forecast models. The purpose of a forecast model is to estimate future river flows and elevations based on observed or forecast amounts of rainfall. In flash flood situations, certain portions of the forecast hydrograph are more important than others. Accurate forecasts of the rising limb, the time to hydrograph peak, and the magnitude of the peak are critical. These are the elements of model output that have the most impact on the flood warning. The model implemented in a flood warning system must consistently perform well in these three areas.

(a) Before model selection, the very important element, rainfall estimation, must be considered. The volume of water under the rising limb of a flash flood hydrograph is primarily surface runoff. Basins with short response times are often characterized by low infiltration rates and steep slopes, which efficiently generate runoff. Because these basins efficiently generate runoff, especially during periods of high intensity rainfall, the volume of runoff is very sensitive to the volume of rainfall. This implies that the output of a flash flood forecast model will also be very sensitive to the rainfall inputs. Nemec (1984), for example, indicated that runoff simulation was 10 times more sensitive to a 5-percent change in precipitation input than to any other model parameter. Sorooshian (1988) also suggests that, for intense storms, the effect of rainfall variability on runoff behavior predominates over that of the basin structure, so much so that the effects of basin structure are difficult to separate.

(b) Flash flood forecast sensitivity to rainfall inputs serves to emphasize the importance of establishing a good measurement system first. The phrase commonly heard in the computer industry, “Garbage in, garbage out,” is equally applicable to flash flood forecasting. Good model performance, no matter what model is used, cannot be expected without a good measurement system. The implication for forecast system design is to invest in the measurement and detection systems first, then consider hydrologic models.

(c) Many different hydrologic forecast models are in use. The most commonly used models in local flood warning systems fall into two categories: simple index-type models and conceptual rainfall-runoff models. Index models keep a running index that reflects current moisture conditions. The moisture index, a “time of year” index, current rainfall, and rainfall duration is generally all that is needed to estimate surface runoff with these models. Conceptual models "embody a series of functions which are considered to describe the basin processes involved" (Linsley, Kohler, and Paulhus 1982). Conceptual models attempt to provide a more "physically-based" approach to basin modeling by more explicitly accounting for evapotranspiration, interception storage, retention storage, infiltration, surface runoff, percolation, interflow, etc.

(d) Table 4-2 shows the most widely available models for local flood warning systems.

**Table 4-2**
**Flood Forecast Models**

| Index Models | Conceptual Models |
|---|---|
| API | Sacramento Soil Moisture Accounting |
| ADVIS | HEC1-F |
| Flood Advisory Tables | |

**API Model.** The API (Antecedent Precipitation Index) Model (Sittner, Schauss, and Monroe 1969) was developed by the National Weather Service and has been used in various forms since the 1950's. The antecedent precipitation index reflects the current soil moisture based on recent rainfall. A high index means high soil moisture content, while a low index indicates dry conditions. The API for a given period is used with a rainfall-runoff relationship, the rainfall amount, and the storm duration to estimate runoff. A unit hydrograph is applied to distribute the runoff. At each computational period, the index is updated based on the additional rainfall and by a seasonally dependent factor. The seasonally dependent factor empirically accounts for changes in the rainfall-runoff relationship due to seasonal changes in evapotranspiration, infiltration, etc.

Complex basins can be modeled by applying the API technique to individual subbasins that are hydrologically homogeneous. Outflows from subbasins can be routed downstream and combined with other tributary flows and inflows calculated by the API model for local areas.

Many versions of the API model exist. Most National Weather Service River Forecast Centers that use API have added modifications to "customize" the technique for conditions in basins within their area of responsibility. At least eight different implementations of API are used by the National Weather Service.

The API model is simple and relatively easy to understand and adjust. Forecasters can easily change model parameters or model runoff based on assessment of the current event to improve model performance.

**ADVIS.** The ADVIS program (Sweeny 1988), developed by the NWS for local flood warning, includes an API model as it is primary hydrologic forecast technique. (All NWS implementations of API are available in ADVIS.) ADVIS is a simplified implementation of hydrologic modeling that produces output appropriate for the *local* user depending upon what type of information is available. For example, ADVIS output includes:

- *Categorical forecasts* for ungaged watersheds. Categorical forecasts are general forecasts of "minor," "moderate," or "severe" flooding based on the antecedent precipitation index and rainfall estimates.
- *Crest stage forecast*. ADVIS will generate a crest forecast if the unit hydrograph peak is available.
- *Forecast hydrograph*. Where the complete unit hydrograph is available, ADVIS generates a complete forecast hydrograph.

The ADVIS program is intended to address relatively simple hydrologic situations at the local level.

**Flood Advisory Tables.** Flood advisory tables are used to provide a quick estimate of peak stage forecasts using indices produced by the API or other modeling techniques. The tables are computed in advance for a variety of antecedent conditions. The current index can be computed onsite or provided by a local NWS office. Local users apply the current index with the latest rainfall estimate to the table to determine the estimated peak stage. An estimated time to peak is usually available based on previous analysis of basin response times.

**Sacramento Soil Moisture Accounting Model.** The Sacramento Soil Moisture Accounting Model (Burnash, Ferral, and McGuire 1973) is a conceptual model designed as a comprehensive representation of the hydrologic processes of the upper soil mantel. Figure 4-3 shows how the various representations of these hydrologic processes are linked together. Runoff calculated for each period is distributed using a unit hydrograph.

Each hydrologic process is represented by a function or series of functions with adjustable parameters. The model is calibrated with historical rainfall and stream flow data by adjusting parameters until the model output adequately represents basin response. The model is applied to individual basins that are hydrologically homogeneous. Complex

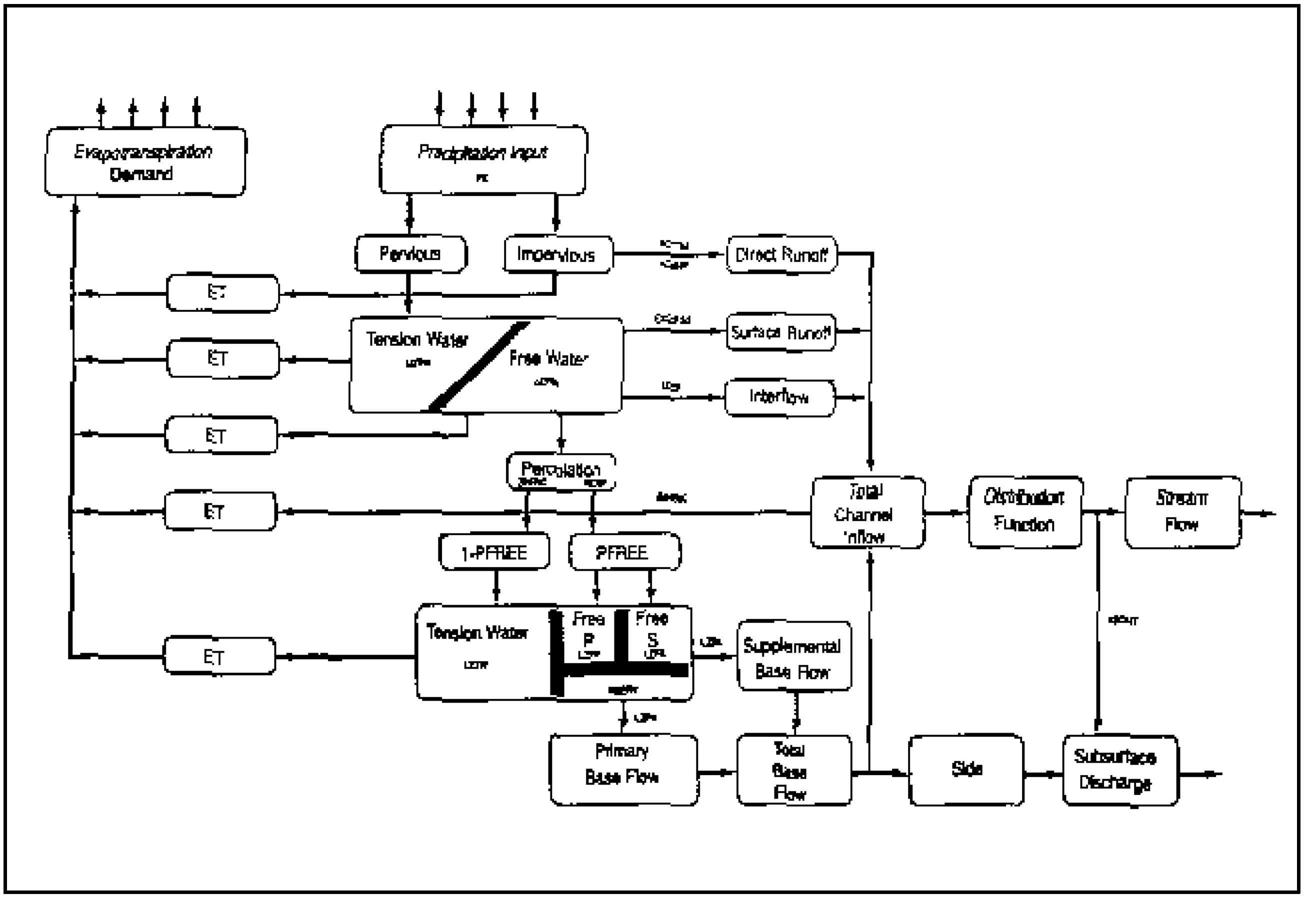


**Figure 4-3. Sacramento soil moisture accounting model**

basins are modeled by combining outflows from individual basins using a variety of available routing techniques.

**HEC1-F.** The Hydrologic Engineering Center (HEC) has developed a forecasting system (Pabst 1986; USACE 1989) for COE offices that is also available for local flood warning systems. The forecast technique uses an initial and uniform loss rate to compute runoff, which is applied to a unit hydrograph to produce a basin forecast. Results from each basin can be combined and routed to develop forecasts for complex systems. HEC1-F uses observed stream flow to set proper loss rate parameters.

HEC1-F can be calibrated relatively easily. Most of the necessary parameters can be easily obtained from maps. Infiltration parameters and certain characteristics of the unit hydrograph can be estimated initially. During a flood event, HEC1-F evaluates model performance against observed stream flow and automatically adjusts the appropriate parameters.

HEC1-F is the forecast version of HEC-1, a widely used hydrologic design tool. Many different public and private organizations throughout the United States have used HEC1 to generate flood hydrographs for a variety of purposes from bridge design to flood plain mapping. As a result, many local engineers understand the model and the transition to HEC1-F is relatively easy.

(2) Quantitative Precipitation Forecasts. Flood forecasts based on rainfall observations will likely underestimate future flood flows if the forecast is released while it is still raining. Sequentially forecasting floods based on observed rainfall only results in “stair-step” forecasts. Each forecast is higher than the previous ones due to the incremental rainfall observations at each timestep. To avoid “stair stepping,” forecasts of future rainfall (quantitative precipitation forecasts or QPF) are used.

(a) Using QPF's along with the observed rainfall provides a more realistic look at possible flood elevations. Not only is the effect of what has already occurred included in the forecast, but what the effect of additional expected rainfall for the remainder of the storm is also included. See Appendix D for an example quantitative precipitation forecast message.

(b) Another way to assess the impact of future rainfall is to test several different future rainfall scenarios. For example, the forecaster can examine the effect of 25 mm (1 in.) of additional rain in the next hour, 50 mm (2 in.) in the next hour, 76 mm (3 in.) in the next hour, etc., on forecast flows by applying these rainfall scenarios to the hydrologic model. The sensitivity of the forecast to the different rainfall scenarios can provide insight into the types of warnings that might be necessary.

(c) If the model indicates that the current hydrologic conditions are extremely sensitive to small amounts of additional rainfall, a set of aggressive warning and preparedness activities might be called for. If the models indicate that large variations of future rainfall will not cause significant increases in forecast flows, emergency officials may choose to watch the situation closely rather than activate emergency plans.

(3) Model Selection. How to choose the “appropriate” hydrologic model is often debated. A widely cited study by the World Meteorological Organization (WMO 1975) indicated that the API technique, the Sacramento model, and the Streamflow Synthesis and Reservoir Regulation (SSARR) (USACE 1991) model all gave about the same results in humid climates. However, explicit soil moisture accounting models like SSARR and the Sacramento model were clearly superior to the API model for arid and semiarid climates. In humid environments, soil moisture conditions are less variable than in arid or semiarid climates. The added complexity of the explicit soil moisture accounting models to handle wide ranging conditions does not contribute significantly to model performance when conditions are relatively stable. However, when conditions are rapidly changing, some researchers have found that explicit soil moisture accounting models offer a significant performance advantage (Kitanidis and Bras 1980).

(a) When reviewing studies comparing the complex explicit soil moisture accounting models with simpler index approaches, an important insight was noted (Sittner 1985). While the simpler models performed well statistically, compared with the explicit soil moisture accounting models, significant deviations occurred at key points. These deviations, while significant, were rare and tended not to affect the overall statistics. However, the deviations were frequently observed when extreme hydrologic conditions existed. The complex models could manage the extremes where the simpler approaches were not capable. These rare events are precisely the events that offer the greatest potential for hazard mitigation.

(b) The choice of models in specific situations remains difficult. After the analysis of which model performs the best for a given basin, it ultimately depends upon the capabilities and resources of local users. Complex models requiring a high level of support might be appropriate in cases where local skills and resources can handle it. However, the same model may be entirely inappropriate in situations with lower levels of local hydrologic skill and resources.

(c) To summarize proper selection, one must choose:

- A model that is within the capabilities of the local user to understand, operate, and maintain,
- A model that is appropriate for the local hydrologic regime, and
- A model that will provide the best estimate of the rising limb, the time to peak, and the flood peak.

## 4-3. Flood Warning and Dissemination

A key element of any flood warning system is how users and local officials are informed that dangerous conditions may be developing. Audio alarms and flashing video displays alert the microcomputer operator that alarm conditions have been detected. Voice dial-out systems are turned on to “call” key officials and provide a synthesized voice warning via telephone. Beeper systems can be activated to alert key personnel. Dial-out and beeper systems are especially valuable if alarms are detected during the night or during the weekend when the computer system may be unattended. Wall size displays can be used as back drops for television broadcasts. Television quality video output can also be generated by the microcomputer for direct distribution over broadcast or cable television systems.

*a*. Once emergency personnel have been activated, mass dissemination techniques come in to play. Radio and television can be effective warning tools, especially during regular broadcast hours. National Oceanic and Atmospheric Administration weather radios can also be effective dissemination tools for local warnings if the local agency has an effective working relationship with, and the necessary communication links to, the National Weather Service.

*b*. Door-to-door forecast dissemination can be used if there is enough time without unnecessarily endangering emergency personnel. Sirens and public address systems can also be used to get the word out.

*c*. One must be cautious when using sirens. Sometimes siren systems are used for multiple purposes. Different siren codes are used to alert for different emergencies. In the Midwestern United States, sirens are commonly used for tornado warnings. If sirens are also used for flash flood warnings, extreme care must be taken to eliminate confusing signals. The response for a tornado warning would be to go to the basement. However, the basement is not the place to be during a flash flood. Clearly, signals for these two events must be immediately and unmistakably distinguishable.

(1) The siren example illustrates that an extremely important element of flood warning dissemination is the content of the warning message. It must be clear and unambiguous. Response to a flood warning improves as the message becomes more specific.

(2) To effect a response, the message recipient must feel that he or she is in jeopardy. The recipient must personally feel threatened by the coming event to be motivated to take action. Table 4-3 shows an example (Barrett and Davis 1988) of how a forecast message varies from general to specific.

**Table 4-3**
**Examples of Flood Warning Specificity**

| | | |
|---|---|---|
| **General** | 1. | Flood warning for Adams County. |
| | 2. | Minor flooding expected in Adams County. |
| | 3. | Minor flooding expected in Adams County this morning. |
| | 4. | A crest of 25.0 feet is expected on Adams Creek in Adams County at 6:00 p.m. |
| **Specific** | 5. | Flooding is expected between Adams Street and Eve Road tonight between 6:00 p.m. and midnight. All houses bounded by these streets will flood tonight. |

Note: 7.6 m (25 ft)

*d*. There are a number of attributes of a flood forecast that, when included, enable increasingly specific and efficient responses to the impending flood.

(1) Location. The location of the impending flood is generally the first element that must be included. Without some mention of location, message recipients probably will not react until they actually see the water rising - losing valuable response time.

(2) River or stream in flood. Identification of the specific river or stream that will flood provides an additional level of information to act on. Those living near the water courses mentioned will likely pay more attention to developing conditions and take action.

(3) Time of flooding. Mentioning the expected time of flooding gives warning recipients a better idea of how much time they have left to prepare and what kind of activities that they have time to do.

(4) Crest of flood. The eventual maximum elevation of flooding defines the expected area of inundation. Response activities can be focussed on those structures within the identified flood area. Evacuation orders can be more specific and be confined to areas affected by the high water.

(5) Time of flood crest. The time of peak flooding, along with the crest forecast, allows emergency officials to finetune their efforts further. The exact timing of the arrival of the crest may give vital insights on how long a particular access/egress route will be available for evacuations.

(6) Time flooding starts. The time that flooding begins is most important to the occupants of the lowest portions of the flood plain. A crest forecast for midnight may not be valuable information to flood plain occupants that experience high water hours before the crest occurs.

(7) Time reaching specific locations and elevations. The availability of the complete hydrograph showing the time each flood elevation is reached allows emergency officials and floodplain occupants to choreograph their activities accordingly.

(8) Time of flood recession at specific locations and elevations. Knowing the time flood waters will recede in each location of the floodplain enables emergency officials to efficiently reenter and secure the flooded area.

(9) Time flooding ends. The time the flood completely recedes signals the end of the immediate emergency and allows officials to coordinate reentry and recovery activities.

(10) Identification of Special Hazards. Unusual backwater effects, flow bottlenecks that cause debris dams, and flows that "short-circuit" the natural channel at certain elevations and/or velocities are all "out of the ordinary" flooding but present a very real and often unforeseen challenge to emergency officials. Early identification of these events can further prevent damage and loss of life.

*d.* The attributes of a flood warning cover the full range of sophistication possible in a local flood warning - preparedness program. At the simplest level, providing a general location of impending flooding (e.g., Level 1 in Table 4-5) requires the least sophistication - perhaps just listening for a flash flood warning on the radio. To supply a complete flood hydrograph and identified areas of inundation (e.g., Level 5 or better in Table 4-5), a complete hydraulic engineering study of the floodplain and an automated local flood warning system with hydrologic/hydraulic modeling capabilities may be required. An example of a detailed, site-specific flash flood warning is included in Table 4-4.

**Table 4-4**
**Example Flash Flood Warning**

*Within the last three hours, rainfall amounts of 5 to 10 inches have been reported over the watershed of Deer Creek, which is about 25 miles northwest of Oil Town. The runoff from this excessive rain will enter the Little River below Devil's Dam and produce virtually a wall of water as it passes through Oil Town in about two to three hours. Persons in Oil Town should be alerted and those on the east bank who are within 500 yards of the river should be evacuated immediately. The River View addition in the bend of the river in the south part of town will be flooded with 3 to 8 feet of water and the people in River View should be evacuated within the next two hours. (McLuckie 1974)*

Note: 127 to 254 mm ( 5 to 10 in.), 40.2 km (25 miles)
457 m (500 yd), 0.9 to 2.44 m (3 to 8 ft)

## 4-4. Emergency Response Plans

*a*. Emergency response plans play a key role in any flood warning - preparedness plan. No matter how elaborate a flood recognition system is, benefits from a plan cannot be realized without a workable response plan. The responsibility for developing the emergency response plan lies with the local sponsor who is ultimately responsible for its success or failure. The Corps provides essential technical input, guidance, and review to assure a reasonable plan is developed and implementable.

*b*. The lead time available, accuracy, specificity, and the reliability of the forecast and warning system dictate the types of response actions that take place. More lead time provides more opportunity to take damage-reducing actions. Higher accuracy, increased specificity, and better reliability means floodplain residents can focus attention on the exact areas and elevations expected to flood, thereby making response actions more efficient and effective.

*c*. Preliminary response actions developed, as previously described, should be finalized. A detailed description of the feasible emergency response actions for each area subject to flooding, accounting for the uniqueness of the flood threat and potential risk associated with each area of concern should be developed. Make a careful inventory of the information required to carry out specific actions, and develop or obtain information not previously considered.

*d*. Emergency response actions are generally carried out in levels as the flood situation progresses. The number of levels in the progression depends on the size and type of watershed in addition to warning time. Levels could correspond to rainfall total depth or intensity for flash flood situations or stage at key locations for nonflash flood situations. Table 4-5 is an illustrative example of potential levels of response and associated actions.

## 4-5. Continuous Plan Management

*a*. The existence of an emergency plan does not, by itself, equate to effective flood response. The process of thinking through a response to a flood scenario is probably more important than the plan itself. The plan development process establishes a dialogue between the emergency officials of different agencies. Problems are identified and appropriate response strategies are discussed and evaluated. Participants become more familiar with each other and with the emergency actions required when disaster strikes.

*b*. The emergency plan is a dynamic document that should serve as the first step toward exercises, drills, and increased flood/disaster awareness (Neal and Lee 1988). A sports analogy to the emergency action plan is the game plan. Coaches review an upcoming opponent and devise a strategy or response plan to counter what the opponent is expected to deliver. Practice sessions are held to repeatedly execute and reexecute various elements of the response plan until each action is executed smoothly and efficiently.

*c*. Another element of maintaining an effective emergency response plan is to make certain that it is up to date and accurate. Communities are highly dynamic. Personnel change every day. New buildings and roads are constructed. Old buildings are torn down. Public policies change and new regulations are implemented. Organizations evolve and internal management relationships change. New equipment, from telephone systems, to radios, to sirens, to computers, is installed. Constant vigilance is required to keep the plan current. If plans are developed then shelved for a year or two, the community investment in the plan is probably wasted.

*d*. Continued emergency response plan management enhancements (USACE 1982a) could include:

(1) Explicit procedures and documentation updating agency personnel telephone numbers, addresses, and responsibilities.

(2) Location of equipment and materials for flood fighting. Sources in the public and private sectors should be identified.

(3) Preprinted brochures describing appropriate actions for the general public. Brochures can be distributed seasonally or during public awareness days or events. Brochure topics include:

**Table 4-5**
**Potential Levels of Emergency Response**

| Level | Situation | Response Action or Institutional Response |
|---|---|---|
| 1 | Flood watch alert | Notify key local official of developing potential flood situation and alert watch |
| 2 | Potential of flooding is significant | Notify local officials responsible for warning dissemination and emergency response plan actions |
| 3 | Flooding is considered highly likely | Flood warning desemination, mobilize emergency personnel for public safety and protection of vital services, make levee/road closures as necessary |
| 4 | Flooding is imminent | Property relocation/removal, evacuation, search, and rescue |
| 5 | Flooding is occurring | Flood fighting, establish emergency medical services, shelters, security measures |
| 6 | Flood is receding | Postflood recovery measures initiated |

(a) Means of obtaining flood information

(b) Procedures for evacuation

(c) Flood fighting procedures

(d) Recovery and reoccupation procedures

(4) Preprinted newspaper inserts, seminars, and workshops can also be used to distribute information and increase awareness.

(5) Periodic drills.

(6) Periodic evaluation and modification of the plan

(7) Negotiation and renewal of contracts, interjurisdictional agreements, memoranda of understanding, and other implementation agreements as necessary.

*e.* Repetition, repetition, and repetition are often the three most important elements of game day preparation. The same concept is valid for an emergency response plan for "upcoming" flood events. The more a plan is practiced, the higher the probability of success when the "game" begins.

## 4-6. Plan Selection

Based on the information developed from the previous described analysis, evaluate the enhancements and their accomplishments. Compare plans, consider the appropriate level of technology described in Section a and select a flood warning - preparedness plan for recommendation. Develop a detailed description of the elements and components of the recommended plan including the cost and realistic accomplishments of the plan elements. Document the justification for the plan as described in Section b and include a description of all the assumptions made regarding the benefits of the recommended plan.

*a. Appropriate technology*. In any flood warning and/or forecast system, it is important to use technology appropriate to the situation. Complex technologies employed in situations without local skills, resources, and long-term operational commitment may quickly lead to system failure. Conversely, it might not be appropriate to use simple stream level alarms to protect high-value property that could be moved, given enough time. Simple river level alarms might not yield enough time to respond, leading to unnecessary losses of life and property.

(1) Appropriate technology considerations should be reviewed extensively during system design. These considerations should also be reviewed during the life of the system to account for evolving local capabilities.

(2) When flood warning systems are designed, sometimes the first consideration is what hydrologic model to use. Often the choice of model, or whether a hydrologic model will be used at all, should be considered last. The reason is that hydrologic modeling is still very much an art as it is a science. The models themselves need considerable attention. Modeling results often demand the eminent judgement and interpretation of a trained hydrologist, something not always available at the local level. Hydrologic models often require years of historical data to be properly calibrated to local conditions. Most of the time, these data are not readily available and the first calibrations are approximate. Under these circumstances, the initial forecast results must be used with great caution.

(3) Even where considerable data are available for initial calibration, the first forecast results must be used with care. Each rain gage network has its own unique characteristics as to how well its measurements represent areal rainfall. These characteristics become imbedded implicitly in hydrologic model parameter estimation during the calibration process. If the operational network is different from the network used in calibration, forecast errors may result since the operational network will have its own set of characteristics and abilities to represent areal rainfall. Therefore, frequent recalibration is often required as the database for the operational network grows.

(4) Because of these problems, the hydrologic forecasting component can be the least reliable portion of the flood warning system in its early stages. This is unfortunate. Once the hydrologic forecast model is installed, it generally becomes the focus of attention. If it does not work well, skeptics will say that the entire flood warning system does not work. If this happens early on before users have a chance to understand the system and gain confidence in it, the system may never have a chance to succeed. System credibility is critical, since many life and death decisions may be made based on it.

(5) To avoid this problem, a staged implementation of the flood warning system might be more appropriate. The basic data acquisition system including measurement, transmission, and data handling at the base station is the portion of the system subject to the least amount of uncertainty. It is the easiest to understand and gain confidence in. A minimum number of rain- and stream gages may be installed initially and additional gages added later as gaps in the data become apparent. By implementing this portion first and allowing users to gain confidence, the foundation is being laid for the future addition of gages and hydrologic modeling, if appropriate. The database gets a chance to develop so that calibration can take place using the same network that will be used operationally. Should the models produce mediocre results at first, the underlying confidence remains and users will realize that it is only the hydrologic modeling portion that needs improvement.

(6) Once the hydrologic forecast model is properly calibrated and becomes integrated into the forecast system, it can become a vital decision-making tool. Forecasts can be made using measured rainfall and the results can be evaluated. More importantly, alternative scenarios of future rainfall patterns can be tested. These results can be evaluated and used to test the sensitivity of forecast results to meteorological forecasts. For example, if widely varying meteorologic inputs cause little or no difference in hydrologic model results, decisions could be made with high confidence levels. However, if the hydrologic forecasts were very sensitive to even slight changes in the meteorological forecasts, decisions can be made but decision-makers must be ready to alter strategies quickly should developing conditions warrant.

*b. Plan justification.* It must be demonstrated that the selected plan cost is offset by reasonably attainable benefits. Each emergency response action taken as the result of advanced planning and increased warning time has direct consequences in terms of derived benefits. The anticipated benefits from a flood warning - preparedness program can be categorized and associated with the contributing actions as noted in Table 4-6.

**Table 4-6**
**Example Benefit Categories**

| Category | Contributing Action |
|---|---|
| Reduced threat to life | Barricades, evacuations, rescues, public awareness |
| Reduced property loss | Removal or elevation of residential and commercial structure contents and vehicles |
| Reduced social disruption | Traffic management, emergency services, public awareness |
| Reduced health hazards | Evacuations, public information, emergency services |
| Reduced disruption of public services | Utility shutoffs, emergency services, supplies, inspection supplies, inspection, public information |
| Reduction in inundation | Flood fighting, temporary flood damage reduction measures, technical assistance |

Plan enhancements should be analyzed and evaluated based on general improvements over the existing condition, the cost of each component, and the potential contributions to reducing flood damages and preventing the loss of life. A strict economic analysis including explicitly quantified flood damage reduction benefits is not required. Reasonable estimates of flood damage reduction benefits based on specific actions that can be accomplished in the time afforded and within community resources are required. The warning time made available from enhanced flood warning establishes the actions that achieve beneficial results. There are reasonable limits to what can be achieved in a given amount of time. The “day curve,” shown in Figure 4-4, can be used as a check of the reasonableness of the stated flood loss reduction benefits. This is accomplished by making a comparison between the estimated benefits and the maximum indicated by the curve. It should be noted that the curve shown in the figure is a generic curve. If possible, a site specific curve should be developed to more accurately reflect study area conditions.

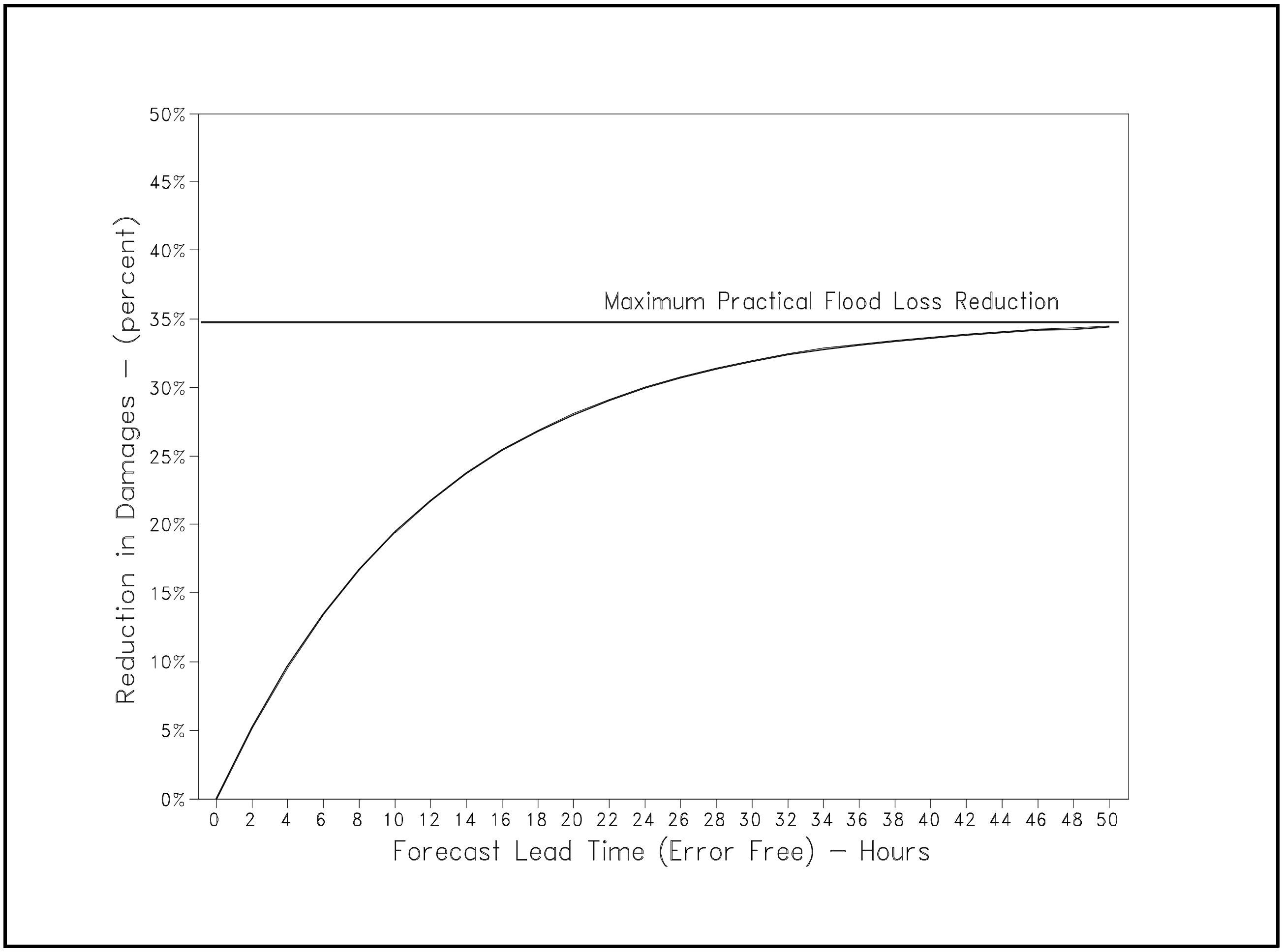


**Figure 4-4. Day curve for flood damage reduction**